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Field trajectories proposals as a tool for increasing work efficiency and sustainable land management

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Abstract. Together with the requirement for higher productivity the average performance and the weight of agricultural machines are increasing. Agricultural land is increasingly exposed to pressures caused by agricultural machinery. The heavy agricultural machinery passes across a field are frequently associated with technogenic soil compaction. Soil compaction is one of the main problems of modern agriculture. From the previous measuring of the traffic intensity it was found 86.13% of the total field area was run-over with a machine at least once a year, when using conventional tillage and 63.75% of the total field area was run-over when using direct seeding technology, with dependence on the working width of the machines. Field passes are inevitable in present agriculture. As a result of the increase of total machines weight, it is necessary to optimize the traffic lines trajectories and limit the entries of the machines in the field. At present, the choice of traffic lines direction is based primarily on the experience of drivers or the practice of farmers. There are a number of influences that affect the machine work efficiency. Monitoring of the tractor, on an irregular 8 fields showed the following results. Eight-meter working width tiller or seeder brought shortening of total length of turns at headlands with the change in trajectory azimuth. For purposes of measuring the monitored tractors were equipped with monitoring units ITineris. An overview of the chosen directions of the trajectories and the lengths of working and non-working passes was obtained. Based on the shape of the plot, the trajectory of the lines was also modelled. Suitable traffic lines directions in terms of the ratio of work and non-work passes were searched.
Based on records of real trajectories, the ratio of working and non-working path ranged between 6.3 and 15.2%. It was obvious from the results that the shortening of non-working passes and turns in comparison with the originally chosen trajectory directions was achieved by optimization. This was especially valid for complex shapes of fields. Trajectory optimization leads to a reduction of total length of path in all cases. The reduction in total length of path ranged from 69.7 m to 1,004.8 m. Changing the length of the working path ranged from 10.9 m to 264.9 m with the change in azimuth. The extension was observed in three cases. The highest part on the change of the overall length of the path presented nonworking rides.

Key words: azimuth, optimization, length of rides.

INTRODUCTION

Contemporary farming systems are associated with negative impacts on soil, which damage both production and non-production functions of soils. Agricultural land is exposed to pressures from tractors, harvesters and vehicles. Field passes are unavoidable in today's agriculture. The primary negative consequence of random crossings on field is soil compaction. The fundamental problem of soil compaction changes determination is the correct interpretation of the results because it is a difficult to measure property whose values are influenced by another properties of soil conditions. The undesirable soil compaction due to agricultural passes becomes a worldwide problem (Håkansson et al., 1988; Gysi, 2001; Chamen et al., 2003; Hamza & Anderson, 2005; Chan et al., 2006). Soil compaction is not a seasonal problem, but the traces of undesirable compaction can also be observed over several years. The soil has different compaction resistance – important factors include grain soil distribution, current soil moisture, soil organic matter content and soil structure. Heavy machinery passes are also reflected in the crop yields and can be observed for many years (Radford et al., 2007).

At present, the choice of trajectory direction is based primarily on driver experience or farmer habits. The implementation of field operations significantly influences the energy performance of agricultural production, expressed in terms of fuel consumption (Boxberger & Moitzi, 2008). As Edwards et al. (2017) reported that trajectory optimising provides important benefits for infield operations. The main benefits include reducing labour, costs, fuel consumption and field trafficking intensity. The intensity passes and associated soil compaction with them includes, besides the economic impact, a number of environmental risks like greenhouse gases (GHGs) from fertilised soils (Tullberg et al., 2018) or erosion treat (Li et al., 2007).

Landers (2000) or Jílek & Podpěra (2005) showed that there are a number of influences that affect the efficiency of machine work. The shape of the field, its size, terrain, obstacles and machine working width play a significant role in this respect. In our conditions, fields where two opposite sides are not parallel can be considered as a standard. Brunotte & Fröba (2007) demonstrated the influence of the different shapes of the field on the need for time for ploughing of the field. The need for time ranged from 100% for rectangular plot (aspect ratio 1: 2) to 117.76% for irregular shape. The navigations methods of agricultural machines moving on field, which are influenced by shape and size parameters of soil blocks, including interaction with the relief of the area of interest, have a significant impact on soil degradation processes, especially on soil compaction (Horn et al., 2000; Botta et al., 2006), including the subsequent long-term persistence of this phenomenon (Berisso et al., 2012). The influence of the shape and size of the soil block in interaction with the movement of the machines is then reflected in the economics of the growing systems and consequently in the overall economic efficiency of the agricultural subject.

Also Jin & Tang (2010; 2011) reported that trajectory planning has great potential to find the best infield path which leads to the field operation costs reducing. This potential increases with adoption of agricultural guidance.

Seufert (1995) considers the analysis of the influence of the size and shape of the field in terms of optimizing work operations as one way to increase the productivity of field crops and reducing of energy requirements and consequently the reducing of greenhouse gases emissions (Hameed, 2014). The main aim of the article is the modelling of optimal trajectories with regard to the shape of the field and the impact assessment on the lengths of working and non-working rides. As Oksanen & Visala (2009) mentioned, path planning is an important part of an intelligent agricultural field machine. The machine can be a traditional tractor driven by a human with a navigation system, an autonomous vehicle or a mobile robot.

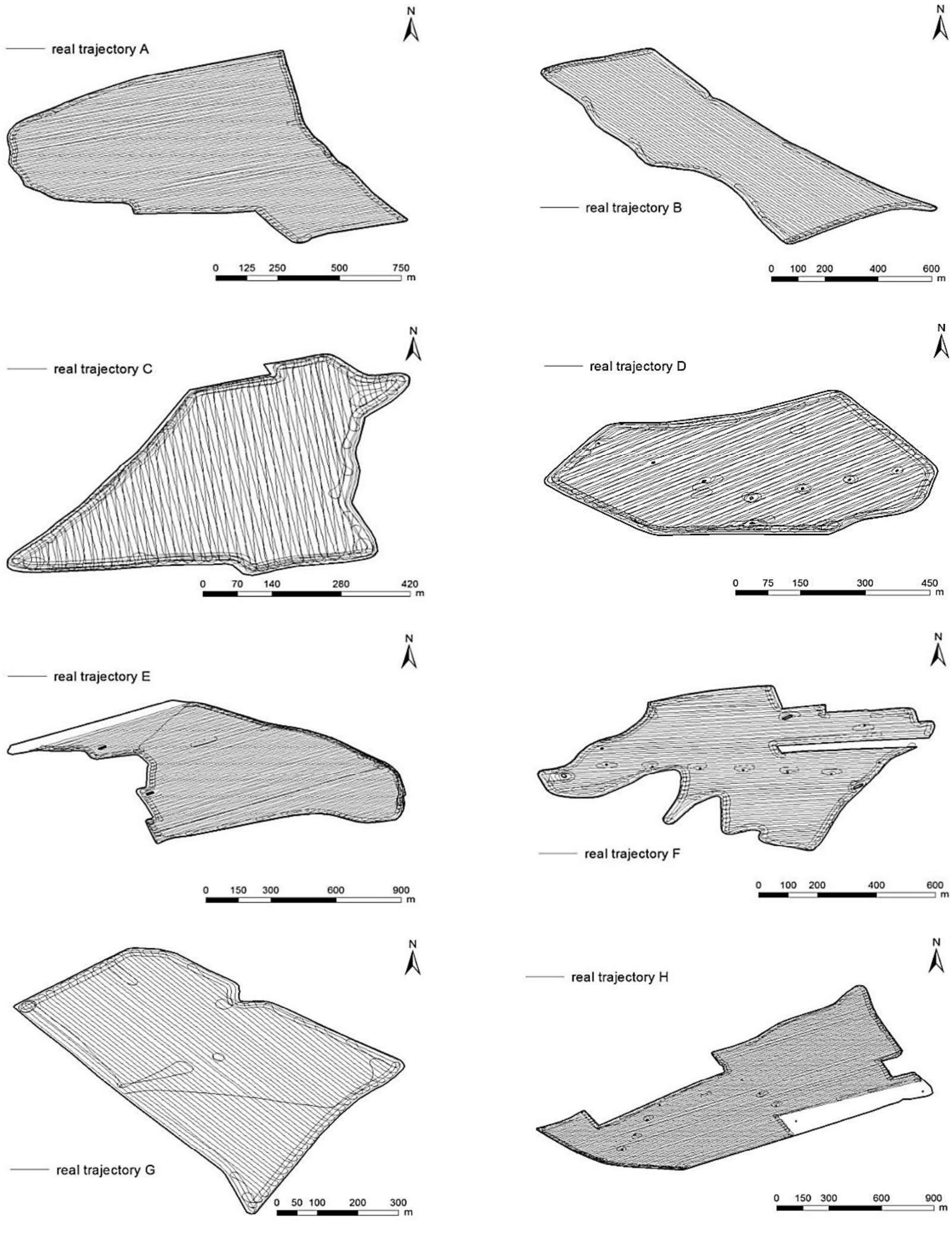

Figure 1. Selected fields and recording of the real direction of machine work trajectories.

MATERIALS AND METHODS

For the evaluation of the movement of machine on field, 8 fields with different shape and acreage were selected. The range of the monitored fields varied from 14.42 to 68.03 ha, (1 ha represents 10,000 m^2).

The tractor was fitted with the ITineris monitoring unit (ITineris Informatikai, Hungary) with a continuous machine position record. On the basis of the driving record, real work trajectories of the machines were obtained (Fig. 1). Data were collected during the work of sowing machine with a working width of 8 m (field A, B, E, F, G, H) and tiller with a working width of 8 m (field C and D).

The next step was the modelling of trajectories for individual fields. The OptiTrail (LeadingFarmers, joint-stock company, Czech Republic) program was used to model the trajectories. For each plot, a total of 180 driving directions were determined with a step of 1°. For the trajectory calculation, the model needs four inputs and parameters, shape of field, which is described by shapefile, working width of machines, number of rides at headlands and minimum turning radius. For the individual trajectories, the lengths of working and non-working rides, length of transport distance, the number of turns and the length of the rides at the headland were calculated. This calculation is created for each azimuth and stored as table. The algorithms attempt to find the shortest possible total path distance for the machine. Direction of the shortest trajectory is stored as A-B line for field guidance. The algorithms attempt to find the shortest possible total path distance for the machine. Direction of the shortest trajectory is stored as A-B line for field guidance. It presents real utilizations of outputs. However the last decision have farmer who decides for trajectory according to the slopes of the fields.

Based on the length of the ride, the most appropriate option was selected and then compared with a variant that was identical to the direction of the ride according to the real record. Software Microsoft office (Microsoft Corporation, Redmond, USA) and ArcGIS 10.4.1 (ESRI, Red lands, USA) were also used.

RESULTS AND DISCUSSION

On the basis of actual trajectory recordings it was possible to determine the real trajectories of work. Based on the model, the parameters of the work rides were calculated for these directions. These values are given in Table 1. For land C and D, lengths were set for two passes due to a double ride during the preparation of the soil. The length of the drive on the headlands for each plot was determined from two hugs of fields.

The ratio between working and non-operating rides ranges from 6.3 to 15.2%. As illustrated by the graph in Fig. 2 with increasing acreage of field the ratio of working and non-working rides has a downward trend. This is consistent with the work of Wagner (2001). He states that the field acreage increasing is associated with a positive effect on reducing the working time per unit area due to a decrease of the time of machine turning. Demmel et al. (2014) report that increasing of the size of the soil block contributes to increasing the efficiency of sugar beet production. On the other hand, the irregular shape of the field may be connected with increase the value of its circumference and thus the occurrence of areas of weed species, which are spread on field around the fringe of fields (Brant et al., 2006; 2008). Increasing the boundaries of field as a contact area with the surrounding landscape increases the risk of application of fertilizers or pesticides outside the boundaries of the field.

Table 1. Model values of travel lengths based on the real azimuth of the rides

Field	Azimuth	Total length of rides, m	Length of working rides, m	Length of turns, m	Number of turns	Length of headland rides, m	Transport, m
A	79°	65,632.14	56,176.61	3,191.88	97	5,905.55	358.10
B	124°	35,223.06	27,662.62	1,842.74	56	5,022.57	695.13
C	165°	21,561.24	15,800.06	2,402.14	73	3,359.04	0.00
	175°	21,698.85	15,835.03	2,237.61	68	3,359.04	267.18
D	65°	20,232.78	15,902.32	1,447.86	44	2,882.59	0.00
	75°	20,599.80	15,993.90	1,283.33	39	2,882.59	439.97
E	72°	58,723.93	48,532.71	2,895.73	88	6,368.83	926.66
F	85°	39,587.26	28,897.48	2,895.73	88	6,744.64	1,049.41
G	130°	27,518.20	21,823.51	1,776.92	54	3,747.85	169.91
H	70°	92,323.62	78,757.01	3,323.51	101	8,382.97	1,860.13

Fechner (2014) has determined the positive effect of optimizing trajectory of work passes to save time when measured on real soil blocks. The most significant time savings resulted from the optimization of trajectories on fields ranging between 10 and 40 ha. On fields with a larger area, the time savings were below 10% compared to the current work rides. In our case, the length of the rides was the main evaluated factor. Fig. 3 shows the changes in working and non-working lengths depending on the selected azimuth. In this example, field D was used.

As can be seen from Fig. 3, the total length of the ride on the field is significantly affected by the number and character of the turns. Transport crossings also contribute to the proportion of non-working rides. This is confirmed by Fechner (2014), which states that optimizing of work trajectories has significantly reduced the need for time to turning of machines at headlands of small and irregular plots. Fig. 4 shows the model trajectory set as optimal, calculated based on the shape of the field.

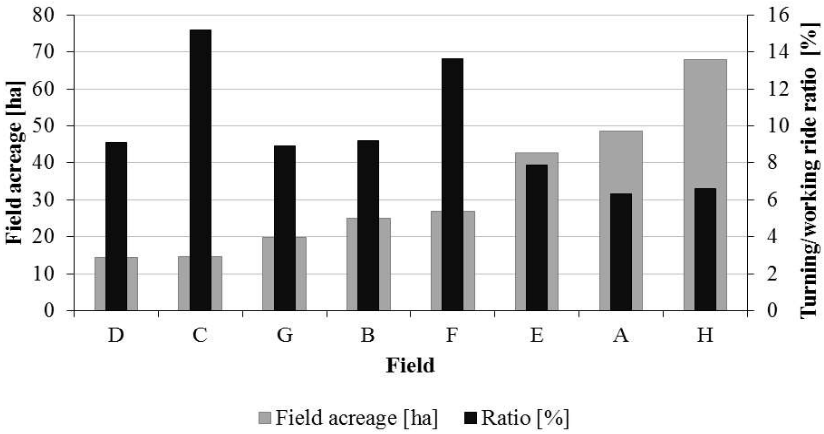

Figure 2. Values of the ratio of working and non-operating rides relative to the land acreage.

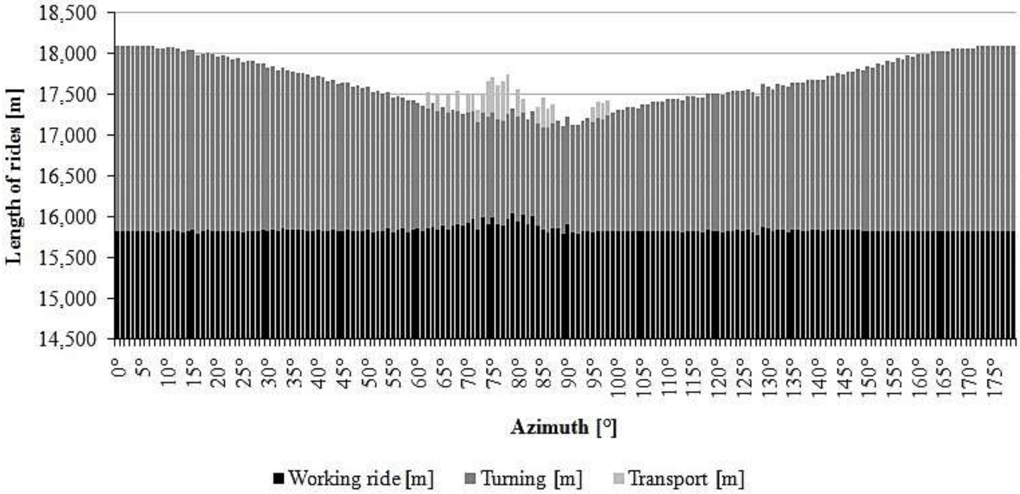

Figure 3. The lengths of working and non-working rides determined for each trajectory azimuth.

It is clear from the outputs that the azimuths of the model trajectories varied from the real routes in all cases. The performance of machines was modified by shape at the same acreage of the soil block. In general, the rectangle with a 1: 2 to 1: 4 aspect ratios is considered to be the optimal shape of the plot in terms of its management. Brunotte & Fröba (2007) stated that the change in shape of the plot from rectangular to irregular shape is associated with an increase in time consumption of more than 17% on a 20 ha field. Fig. 4 shows that the land showed significant shape differences and acreages. The opposite sides were not parallel in all cases. From the operator point of view, it is more difficult to select the optimal driving direction based on an estimate or experience. Table 2 provides an overview of optimized trajectory values. Headland length remains the same. The table shows the ratio of working and non-working rides for individual fields.

Table 2. Values of model rides based on optimized ride azimuths

Field	Azimuth	Total length of rides, m	Length of working rides, m	Length of turns, m	Number of turns	Transport, m	Working and nonworking rides ratio, %
A	90°	65,406.42	56,210.27	3,290.60	100	0.00	5.85
B	153°	34,835.16	27,542.07	2,270.51	69	0.00	9.17
C	45°	20,817.41	15,845.98	1,612.39	49	0.00	10.18
D	89°	20,002.07	15,803.24	1,316.24	40	0.00	8.33
E	73°	58,146.10	48,474.97	2,961.54	90	340.76	6.81
F	83°	39,464.26	28,632.53	2,895.73	88	1,191.36	14.27
G	143°	27,448.53	21,727.31	1,645.30	50	328.07	9.08
H	73°	91,318.82	78,785.44	3,718.38	113	432.02	5.27

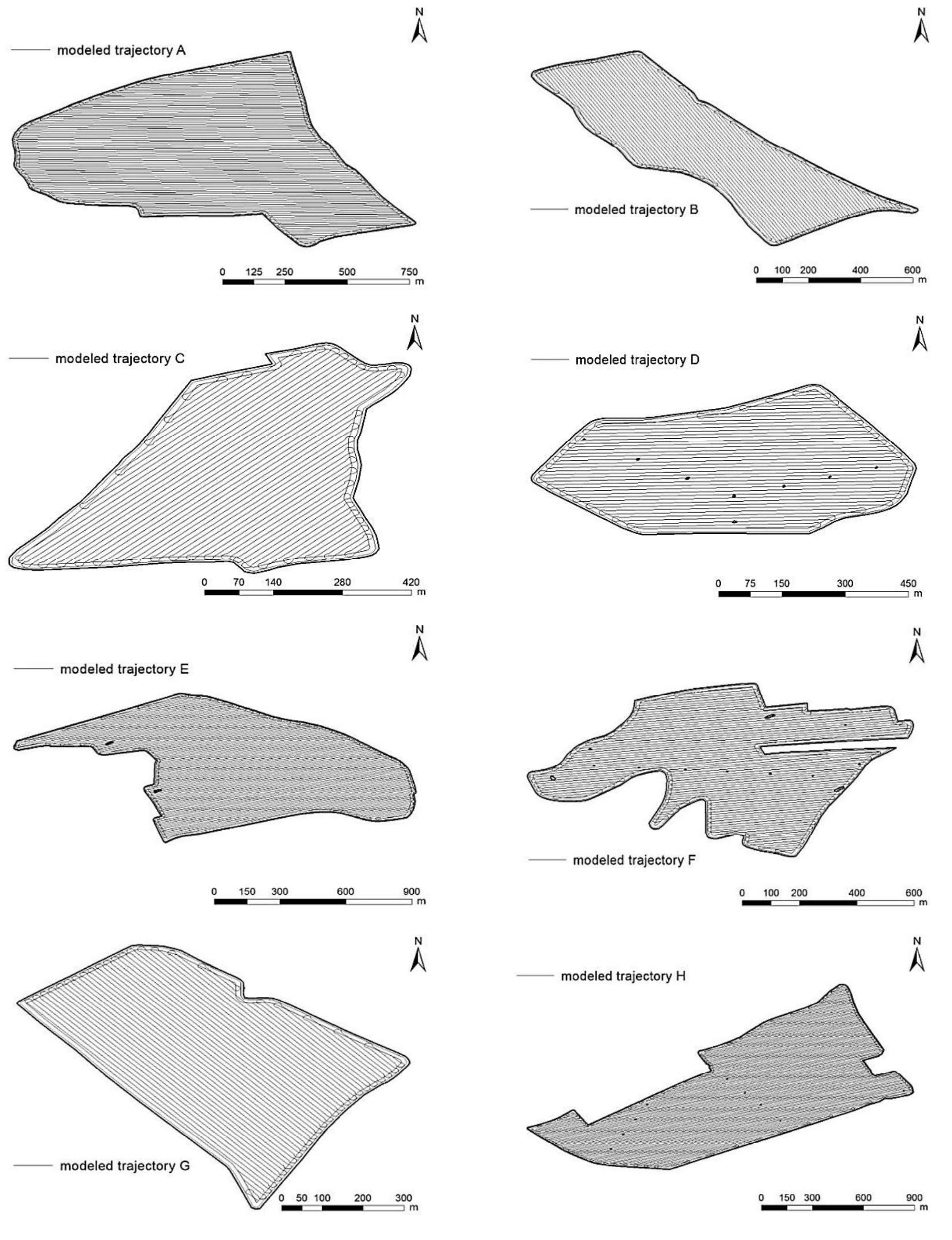

Figure 4. Modelled trajectories.

The number of rotations was reduced and the ratio of working and non-operating rides was improved in comparison with the real situation in all cases with exception of G and F fields. Differences in the ratio between real and model trajectories varied from 7.3 to 35.6%. There was no statistically significant difference between the working and non-operating path ratios of the real record and the model. However, any reduction in costs could ultimately mean economic and also environmental benefits. A slight increase in non-working rides occurred on the fields F and G, however, the total driving length was shortened. Field F presents a complicated shape with a high proportion of turns. The difference in trajectory azimuth was highest for plot C, where the deflection was equal to 120°. For fields B and D, the deflection was 29°, respectively 24°. For other plots, the deflection of the trajectories varied from 1° to 13° against the optimal model. Edwards et al. (2017) also describes a reduction in total journey time when optimizing routes compared to the operator. Bochtis et al. (2013) compared B-patterns against conventional field work patters. They showed reductions in non-working distance up to 58.65% and increases in the area capacity were up to 19.23% when compared with different types of conventional field-work patterns. From the other hand, the rolling terrains of many farms have considerable influence on the design of coverage paths (Jin & Tang, 2011; Hameed et al., 2013; Hameed 2014). Authors presented 3D planning algorithm. As Jin & Tang (2011) presented, the 3D planning algorithm saved 10.3% on headland turning cost during the field tests. Hameed (2014) demonstrates 6.5% reduction in the energy requirements when the driving angle is optimized by taking into account the 3D compared to the case when the applied driving angle is optimized assuming even field areas.

CONCLUSIONS

The results show the direction where modern technical resources can contribute to improving the quality of filed management and reducing adverse effects on soil. The results show that even a minimal change in driving direction can contribute to a reduction in the overall length of the ride on field and also contributes to a reduction in the turning on headlands. This measure contributes to more efficient machine work and reduced soil load. In addition, the results reveal further directions of research activities. The slope of the field does not always allow the optimal direction of the trajectory according to the shape of the plot. Other important elements on the land are, for example, the power lines which need to be bypassed. Route optimization can respect these lines and determine the direction of trajectories. Further work is still needed for the implementation of the sloping model in the calculation of trajectories. Also, from the minimizing of turning and passes point of view of, it seems to be a very interesting topic to align the boundaries of the fields and eliminate the folds from intensive field farming.

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